Fermilab FERMILAB CONF-07-738-E

Recent Results in b Quark Physics at CDF

Sinéad M. Farrington

Dept of Physics, University of Liverpool, Liverpool, L15 5AL, England
**E-mail: sineadf@fnal.gov*

The summer 2007 results in b quark physics in 0.7 to 2.2 fb^{-1} of CDFII data are summarised. Results in b production, mixing, new observations and branching ratio measurements are discussed.

Keywords: Keyword1; keyword2; keyword3.

PACS numbers: 11.25.Hf, 123.1K

1. Introduction

The CDFII detector and trigger system are well suited to gathering samples of the plethora of b hadrons which are produced in the Tevatron collider. The results of summer 2007 represent the diversity of b quark measurements which is possible at a hadron collider, in production, mixing, detection of new states and decays.

2. b Production

In the Tevatron's Run I, both D0 and CDF measured high dimuon cross sections. An analysis of 0.74fb^{-1} in CDFII has yielded a new measurement of the $b\overline{b} \to \mu^+\mu^-$ and $c\overline{c} \to \mu^+\mu^-$ cross sections. A dedicated dimuon trigger isolates a sample of 660,000 opposite sign muon pairs and 440,000 like sign pairs. The two-dimensional impact parameter data distribution is fitted with templates of the $b\overline{b}$ and $c\overline{c}$ signal shape obtained from simulation samples and a prompt template which is obtained from data in order to determine the $b\overline{b}$ and $c\overline{c}$ fractions. A correction is applied for the presence of fake muons using rates measured in the data. A correction is also made for the acceptance and efficiency of the detector and triggers. This yields $\sigma(b\overline{b} \to \mu^+\mu^-) = 1549 \pm 133$pb and $\sigma(c\overline{c} \to \mu^+\mu^-) = 624 \pm 115$pb. The cross section $\sigma(b\overline{b}) = 1618 \pm 148$pb is in agreement with theory expectations.

3. Mixing

The phenomenon of mixing in the B system has been established in the B_d^0 and B_s^0 systems, confirming the interpretation of the propagating states as superpositions of particle and antiparticle into "heavy" and "light" states. Each of these states has

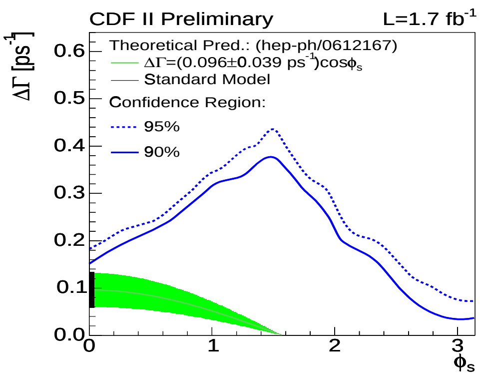

Fig. 1. $\Delta\Gamma_s$ confidence region from angular analysis.

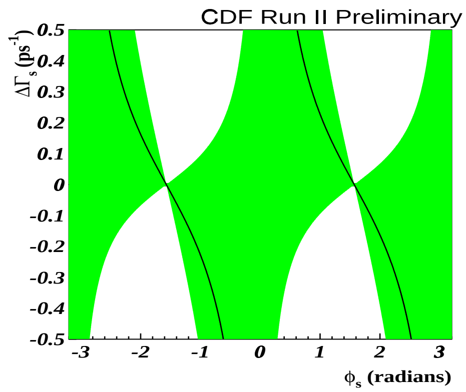

Fig. 2. $\Delta\Gamma_s$ confidence region from A_{CP}.

its own lifetime ($\Gamma = 1/\tau$) and mass. The mass difference (Δm_s) is very accurately measured in the B_s^0 system, but the difference in lifetime ($\Delta\Gamma_s$) and the phase ϕ_s which may modify the Standard Model (SM) value of $\Delta\Gamma_s$ are poorly determined. The heavy and light B_s^0 states can be separated by angular analysis [2] in a simultaneous fit to the mass, lifetime and angular variables in $B_s^0 \to J/\psi\phi$ decays. Allowing no CP violation in the fitter results in $\Delta\Gamma_s = 0.076^{+0.059}_{-0.063}(stat) \pm 0.006(sys)ps^{-1}$, $c\tau_s = 456 \pm 13(stat) \pm 7(sys)\mu m$, $|A_0|^2 = 0.530 \pm 0.021(stat) \pm 0.007(sys)$ and $|A_{\|}|^2 = 0.230 \pm 0.027(stat) \pm 0.009(sys)$. The measured value of $\Delta\Gamma_s$ agrees with the expected value of 0.096ps^{-1} [4]. In the fit configuration which allows CP violation there is an intrinsic bias which does not allow separate determination of $\Delta\Gamma_s$ and ϕ_s due to statistical fluctuations for small event numbers. Therefore a confidence region is provided as shown in figure 1.

An alternative way of accessing ϕ_s is through the relation $A^s_{SL} = \Delta\Gamma_s/\Delta m_s \times \tan\phi_s$ where $A^s_{SL} = (N(\mu^+\mu^-) - N(\mu^-\mu^-))\,/\,(N(\mu^+\mu^-) + N(\mu^-\mu^-))$ is the semileptonic asymmetry of B_s^0 mesons. Using the generic dimuon sample described in section 2 the semileptonic asymmetry for b hadrons can be obtained by applying the same technique of fitting the impact parameter distribution. Again corrections are applied for hadrons which fake muons and detector and trigger acceptance and efficiency yielding $A_{SL} = 0.0080 \pm 0.0090(stat) \pm 0.0068(sys)$. Assuming a negligible asymmetry from B^+ and b baryon decays and correcting for the known B_d^0 asymmetry results in $A^s_{SL} = 0.020 \pm 0.021(stat) \pm 0.016(sys) \pm 0.009(inputs)$. The allowed regions in the $\Delta\Gamma_s$ and ϕ_s plane are shown in figure 2.

In 2007 the first observation of charm mixing was presented by the B factories. CDF also has evidence for charm mixing in an analysis of 1fb^{-1} of data. Charm mixing is highly suppressed compared with that of the bottom and strange sectors because, since charm is an up-type quark, top cannot participate in the mixing loop. CDF has large samples of charm mesons (2.2 million "right-sign" $D^{\star -} \to D^0\pi^-$ and 9.4 thousand "wrong-sign" $D^{\star -} \to \overline{D^0}\pi^-$) making an analysis of such a small mixing rate viable. The wrong-sign decays are the result of either D^0 mixing or doubly Cabibbo suppressed decays. The ratio of the wrong-sign to right-sign events as a function of D^0 decay time probes the charm sector mixing parameters x' and y': $R(t) = R_D + y'\sqrt{R_D}t + \left(x'^2 + y'^2\right) t^2/4$. A fit to the ratio thus yields allowed regions in x' and y' as shown in figure 3.

4. New States

The latest of several observations of new b bound states is that of the Ξ_b baryon in its decay to $\Xi J/\psi$ (with $J/\psi \to \mu^+\mu^-$ and $\Xi \to p^+\pi^-$) [5]. A novel tracking approach is deployed in this analysis which improves the vertex resolution by making a virtual silicon track for the Ξ. The statistical significance of the Ξ_b observation is seven standard deviations and the mass is very accurately measured: $Mass(\Xi_b) = 5792.9 \pm 2.5(stat) \pm 1.7(sys) MeV/c^2$.

In Heavy Quark Effective Theory [6], B mesons can be viewed in analogy to the hydrogen atom resulting in a set of four excited states, denoted $B^{\star\star}$, two of which are expected to be broad and not experimentally visible and two are expected to be narrow. $B^+ \to J/\psi K^+$ and $B^+ \to D^0\pi^+$ samples are used to search for the decays $B^{\star\star} \to B^{(\star)+}\pi^-/K^-$. Neural networks are used to identify the $B^{\star\star}$ and B^+. The Q value distribution, defined as $Mass(B\pi) - Mass(B) - Mass(\pi)$ reveals clean signals for the narrow $B^{\star\star}$ states. Constraining the relative width of the states gives rise to the following measurements: $Mass(B_1^0) = 5725.3^{+1.6}_{-2.1}(stat)^{+0.8}_{-1.1}(sys)MeV/c^2$, $Mass(B_2^{*0}) = 5739.9^{+1.7}_{-1.8}(stat)^{+0.5}_{-0.6}(sys)MeV/c^2$ and $\Gamma(B_2^{*0}) = 22.1^{+3.6}_{-3.1}(stat)^{+3.5}_{-2.6}(sys)MeV/c^2$.

5. B Decays

By a quirk of nature in the coupling strengths, the amplitude of $B_s^0 \to D_s^+ K^-$ is approximately equal to $B_s^0 \to D_s^- K^+$ thus in these decays CP violation can occur in B_s^0 mixing by intererence between the mixed and unmixed paths. A time dependent asymmetry would allow a measurement of this quantity. However the first step to this result is the observation of the decay mode and measurement of its branching ratio. Using a sample obtained with CDF's displaced vertex trigger in 1.2 fb^{-1} of data, a signal is sought using $B_s^0 \to D\pi$ as a control mode. A likelihood fit to the mass and particle identification quantities with background templates taken from simulations, yields a 7.9 standard deviation observation and branching ratio measurement of $BR(\overline{B}_s^0 \to D_s^{\pm} K^{\pm}/\overline{B}_s^0 \to D_s^+\pi^- = 0.107 \pm 0.019(stat) \pm 0.008(sys)$.

The B_c meson signal in 2.2 fb^{-1} has a signal significance of 9 standard deviations. This is obtained using a cut selection which is optimised in the data for significance of the $B^+ \to J/\psi K^+$ signal. CDF's tracking capability leads to a precise mass result of $Mass(B_c) = 6274.1 \pm 3.2 \pm 2.6 MeV/c^2$, confirming lattice QCD expectations.

In the SM, the flavour changing neutral current decays $B \to \mu^+\mu^-$ ($B = B_s^0$ or B_d^0) proceed through loop diagrams and are heavily suppressed. The predicted branching ratio of the $B_s^0 \to \mu^+\mu^-$ is $(3.4 \pm 0.5) \times 10^{-9}$ and the B_d^0 decay is further

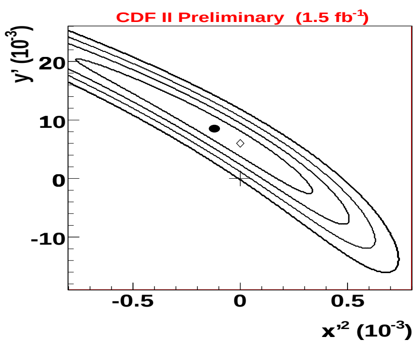

Fig. 3. 95% confidence region for charm mixing parameters.

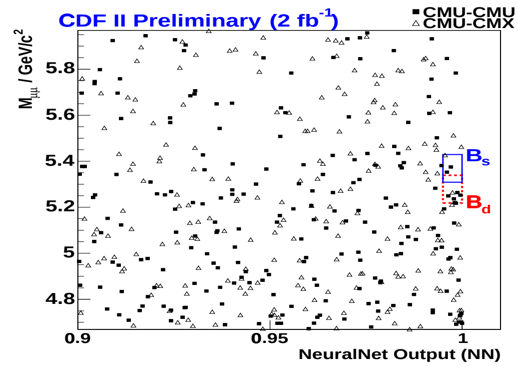

Fig. 4. Invariant mass of $B \to \mu^+\mu^-$ candidates versus neural net output.

CKM suppressed[1] to $(1.00 \pm 0.14) \times 10^{-10}$. These branching ratios are both below CDF's sensitivity and so observation would disagree with the SM branching ratio.

The CDF collaboration has set a limit on the branching ratio of $B \to \mu^+\mu^-$ in 2fb^{-1} of data [3] relative to the $B^+ \to J/\Psi K^+$ control mode. A neural network selects the $B \to \mu^+\mu^-$ signal and suppresses backgrounds. The remaining background is assessed from sideband regions and the relative efficiency and acceptance for the $B \to \mu^+\mu^-$ with respect to $B^+ \to J/\Psi K^+$ are obtained from simulations and data. The branching ratio is obtained relative to the control sample:

$$BR(B_s^0 \to \mu^+\mu^-) = \frac{N_{B_s}}{N_{B^+}} \frac{\alpha_{B^+}\epsilon_{B^+}^{total}}{\alpha_{B_s}\epsilon_{B_s}^{total}} \frac{f_u}{f_s} \times BR(B^+ \to J/\Psi K^+) \\ \times \quad BR(J/\Psi \to \mu^+\mu^-)$$

Here, N_{B+} is the yield of $B^+ \to J/\Psi K^+$, N_{B_s} is the yield of $B_s^0 \to \mu^+\mu^-$ decays, α_{B^+,B^0} are the acceptances and $\epsilon_{B^+,B^0}^{total}$ are the efficiencies for the decay modes. The yields, N_{B+} and N_{B_s}, are corrected by the relative production fractions, f_u and f_s, and the branching ratios in the control sample. In the B_d^0 analysis the calculation omits the f_u/f_s term. The unblinded invariant mass versus the neural net output of the dimuon candidate is shown in figure 4. The resulting branching ratio limits are $BR(B_s^0 \to \mu^+\mu^-) < 5.8 \times 10^{-8}$ and $BR(B_d^0 \to \mu^+\mu^-) < 1.8 \times 10^{-8}$ at 95% confidence level, which are currently the world's best limits.

References

1. A.J. Buras, Phys. Lett. **B566** (2003) 115
2. D. Acosta *et al.*, Phys.Rev. Lett. **94** (2005) 101803
3. A. Abulencia *et al.*, Phys. Rev. Lett. **95** (2005) 221805
4. A. Lenz, U. Nierste hep-ph/0012219
5. T. Aaltonen *et al.* Phys. Rev. Lett. **99** (2007) 052002
6. M. Neubert, Phys. Rep. **245** (1994) 259